EXPLANATORY NOTES

TO ACCOMPANY A

GEOLOGICAL SKETCH-MAP

OF

FENNO-SCANDIA

BY

J. J. SEDERHOLM

HELSINGFORS 1908

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IN this map the author has tried to bring together some conceptions of our present knowledge of the main lines of the geological structure of that region in the north of Europe which is now, on the proposal of Wilhelm Ramsay, generally called Fenno-Scandia, with special reference to its older, i. e. pre-Cambrian formations. The map has already been published in the author's paper on the granites and gneisses of that region (Bull. N:o 23 of the Geolog. Comm. of Finland), but is here issued separately.

The author is well aware of the difficulties of his endeavour. The material upon which the map is based is of very different value for different parts of the region. While some of the most important of these parts have been the object of detailed researches by eminent geologists, there are others which are still very little known.

Those parts of the map which comprise Kola and Russian Carelia have been kindly elaborated by Professor Wilhelm Ramsay; whose long continued investigations in these regions entitle him to speak of them with authority. Large areas, however, are as yet untrodden by the feet of any geologist.

In Finland there are two areas still unexplored: the one a triangle, lying between the towns of Wasa (Nikolaistad), Uleåborg, on the Gulf of Bothnia, and Kuopio in the midlands, the other the district N.E. of Lake Uleå. The mapping out of the region along

the northern shore of the Gulf of Finland cannot be regarded as up to date, since it was made, in part, some 30 to 40 years ago. The greater part, however, of Finland has been mapped out by the present generation of geologists under the guidance of the author of the map and on the same principles. Where therefore the opinions of the geologists of the adjacent countries of Fenno-Scandia differ on some questions of correlation, the present writer will naturally be inclined to lay most stress on the experience thus gained in his own country.

The greater part of Sweden has been very accurately mapped, but at different times and according to widely differing methods and principles. The classification of the older pre-Cambrian rocks of Sweden, which must still be regarded as the official view, resembles still very much that which Hummel proposed about 30 years ago, at a time when it was thought that the stratigraphy of the Archæan was simpler instead of being more complicated than that of the later formations and that the gneisses were, in general, older than the schists. Also the methods followed by the correlation of the Swedish granites has been, as will be seen later, very different from those used in Finland, and the author of the map has therefore been forced, while following, in the main, the valuable maps of Törnebohm and other Swedish geologists, to introduce changes which will seem somewhat radical. He pleads as his excuse that he has kept in close touch with his Swedish colleagues, and has visited personally some of the most important localities in Sweden, which is very similar in its geological structure to his own field of inquiry, and cannot therefore regard the Swedish parts of Fenno-Scandia as entirely foreign to him. He would also point out, that some of the more recent theories proposed by Swedish geologists for explaining the geological structure of the Fundamental Complex of Sweden, as for instance that of De Geer, would introduce even a greater change in the prevailing opinions than his own proposals. The fact that the aforesaid theories met with considerable sympathy among several distinguished geologists of Sweden shows that the opinions of those authorities concerning the pre-Cambrian geology of that country are not yet settled.

For the Norwegian parts of the map the author has used the recent maps of Björlykke, and in the northern part, the maps of Thellef Dahll, Karl Pettersen, H. Reusch, &c. These he has checked by the Norwegian part of the international map of Europe,

the map of Törnebohm of middle Scandinavia, &c. and by information kindly furnished by Dr. H. Reusch. The geologists of Norway, busy with the elucidation of the great problems which they met with among the younger rocks of their country, have so far had little time to devote attention to the study of the pre-Cambrian rocks. It has therefore been necessary here to treat them in a rather summary fashion.

Other matters upon which the material is more deficient than usual, or concerning which different opinions prevail among the geologists of each individual part of the Fenno-Scandinavian region, will be mentioned hereafter.

It is obvious from what has been said that the author does not claim to give anything like a definite and correct representation of the geological structure of Fenno-Scandia. A first endeavour must of course be defective, but he thinks that there can be shown at this stage so many common traits in the geology of that region, that it is desirable to present them on a map and to show how they may be interpreted, on the basis of the knowledge gained especially in the eastern part of the region in question, where the more or less metamorphic sedimentary rocks are much more continuous, and the geology, in general, shows greater and clearer traits, than in the west.

The following method has here been used in mapping and classifying these rocks. They have first been distributed by field work into natural groups, and an attempt has been made by the detailed petrological study of each in turn to ascertain its probable origin. The relative ages of the different formations have then been determined by studying their stratigraphy and contact-relations to each other, especially with regard to those granitic masses which have the widest extension; also the relations of the different rocks to the great orogenetic movements which have affected the region at different times and have impressed on the rocks their widely differing secondary characters. This study has proved the existence in the eastern part of Fenno-Scandia of considerable thicknesses of pre-Cambrian rocks, separated by great unconformities, and has led to the establishment of the classification of these rocks, which will be used later on. It has been put to the test of continued field work and has proved valid at least for the parts mentioned. As already stated the author thinks that several of the formations of Finland can also be traced across the intervening gulf on the Swedish side.

Tentatively presenting this map chiefly for the purpose of serving as a basis for further discussion, the author hopes that it may soon be possible, by the mutual aid of the geologists of Fenno-Scandia, to give another and more correct rendering of its main geological features.

A single glance at the map will show how well defined geologically is that region. Its boundaries have been determined by movements of the crust which began as far back as the Palæozoic era and continued till the Tertiary period, when the escarpment was formed against the Atlantic and the main features of the present relief were outlined. Fenno-Scandia has been cut away from the adjacent terranes by faulting at different times.

The formations shown on the map will now be enumerated and the older of them shortly described in descending order.

Quarternary. This is represented on the map only where the older rock-masses are entirely covered so that their composition is not known.

Tertiary,

Mesozoic,

Permian and Carboniferous and

Devonian sedimentary rocks occur mainly outside of the region in question and it is therefore not necessary here to give any account of these formations. (The Jurassic of Andön in northern Norway is not shown on the map because of its small extension).

Post-Silurian Granite, Syenite, Nepheline-syenite, Ijolite, &c. In this division are included the nepheline-bearing rocks of Umptek and Luijaur-Urt on Kola, Kuolajärvi and Kuusamo in Finland, Alnön by Sundsvall in Sweden and Christiania in Norway, which areas with their pertinent granitic and syenitic rocks, are probably all genetically connected. In Kuolajärvi there has been found lately Alnöitic rocks, ægirine-impregnated limestones and other phenomena closely resembling those observed at Alnön by Sundsvall, while the small districts of Särna in Dalarne and Lake Wettern (not visible on the map) are further links connecting the most distant parts of the same chain of eruptive areas.

In the same colour are also indicated the post-Silurian granites of the Scandinavian mountain-chain, which have taken part in the folding and thrusting, and are possibly somewhat older than the nepheline-bearing rocks.

The post-Silurian gabbros, olivinites, &c. of the mountain-chain,

are closely allied to these granites, and are also more or less metamorphosed.

Silurian and Cambrian. In this division are placed the non-metamorphic sedimentary rocks of the Silurian and Cambrian ages in the region S.E. and E. from the mountain-chain (including the Eo-Cambrian „Blue Clay") and such metamorphic rocks of that chain which are probably to be correlated with them. The representation here given tries to reconcile, as much as possible, the conflicting views of the geological authorities on opposite sides of the state boundary which intersects Scandinavia along its geological backbone. Data for the northernmost parts of Norway have been furnished also by V. Tanner, of the Geological Survey of Finland, who has worked in that region during the last years.

Pre-Cambrian of the Scandinavian uplands (Sparagmite, Seve Formation, &c.). Raipas and Gaisa. The representation of these formations on the map labours under still greater difficulties because of the dissensions concerning them among Scandinavian geologists.

Part of the rocks which Törnebohm describes as overthrusted pre-Cambrian, the Norwegian geologists regard as Silurian sediments and eruptives in a highly metamorphic condition. The interpretation given on the map follows as far as possible the authorities which are most at home in each particular field of inquiry, but it is of course impossible in that way to give quite a consistent representation of the geological features of the Scandinavian mountain range.

Where the pre-Cambrian sediments of that tract are still unmetamorphic, they often show a marked resemblance to the Torridonian sediments of Scotland. This is particularly true of the Sparagmite of Norway and Sweden, a feldspathic, often coarse-grained sandstone.[1] There are occasionally sandstones also in the northern parts of the mountain-chain in Enontekis in Finland, which very much resemble the Torridonian.

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[1] The remark in Bull. Comm. Géol. de Finl. N:o 23, p. 92 concerning the similarity between the Jotnian and the Torridonian refers to their general stratigraphical position and to the absence of signs of regional metamorphism in either of them. The primary petrological characters of the Torridonian, with which the author became acquainted in the summer 1907 on Loch Assynt and Glen Coul, remind one still more of the Sparagmite and adjoining rocks than of the Jotnian rocks proper.

Jotnian Sandstones. Under the name of Jotnian have been grouped together those pre-Cambrian rocks certainly, or at least

Fig. 1. Jotnian sandstone with ripple-marks. Boulder found in Bromarf in southern Finland. $^1/_{10}$ nat. size.

Fig. 2. Jotnian sandstone from Kauhajoki in western Finland, showing crossbedding. $^1/_4$ nat. size.

probably, older than the Sparagmite, which are devoid of those signs of regional metamorphism which are so conspicuous among the older rocks of that same region. In this division are placed the

sandstones of Dalarne, Gefle, and Ångermanland in Sweden (the last not visible on the map because of its small extension), of Björneborg, on the Gulf of Bothnia, and Isojoki and Kauhajoki in Finland, and of the eastern shore of Lake Onega in Russia. There are also numerous boulders of the same rock, though not outcropping, on the Isthmus between Lake Ladoga and the Gulf of Finland.

Jotnian Diabases. In Dalarne, Ångermanland, near Björneborg and on Lakes Ladoga and Onega there are diabases, most of them olivine-bearing, connected with these sandstones, penetrating them and overlying them in beds.

Other diabasic or rather „anorthositic" rocks, viz. the labradorites of Ångermanland and southern Finland, are older than the Jotnians sandstones just mentioned and even than the rapakivi-granites which penetrate them and which to a large extent have assimilated fragments of them.

Rapakivi-Granites. These granites are distinguished by a peculiar, porphyritic texture, the greater crystals often being surrounded by a zone of plagioclase (Fig. 3). These rocks gradate into true quartz-porphyries and also into common granites. The former occur as dikes, sills or, as is the case on the island of Hogland, in the Gulf of Finland, as sheets. That sheet of quartz-porphyry is here separated from the underlying Archæan rocks by quartzitic sandstones and conglomerates, which may be regarded as forming the lowest part of the Jotnian. In Ångermanland in Sweden, again, the typical Jotnian sandstone is seen resting upon the rapakivi-granite.

Rocks singularly similar to the rapakivi-granites of Fenno-Scandia, and also connected with labradorites and pre-Cambrian sandstones, occur among the pre-Cambrian rocks outcropping in Wolhynia in western Russia, while, on the other hand, the so-called rapakivi of the Urals shows very little similarity to the Finnish rocks.

Rocks whose primary textures may have been similar to those of the rapakivi-rocks are not uncommon among the older granites of Fenno-Scandia, which, however, are so markedly distinguished in their degree of metamorphism, their contact-relations and in other details from the rapakivi-granites. Again, the granitic rocks of the Christiania basin described by Brögger sometimes exhibit the textures of the rapakivi and have been classified by him under the

same head. But in this case the name must be used in a petrological sense, not a geological. Then, while the Christiania granites are of post-Silurian age, the pre-Cambrian age of the rapakivi-rocks is at least very probable. As already stated they occur in close connection with sandstones whose pre-Cambrian age is almost certain. The nearest outcrops of Eo-Cambrian (i. e. pre-Olenellus) blue clay of the Carelian Isthmus are only about 70 km (50 miles)

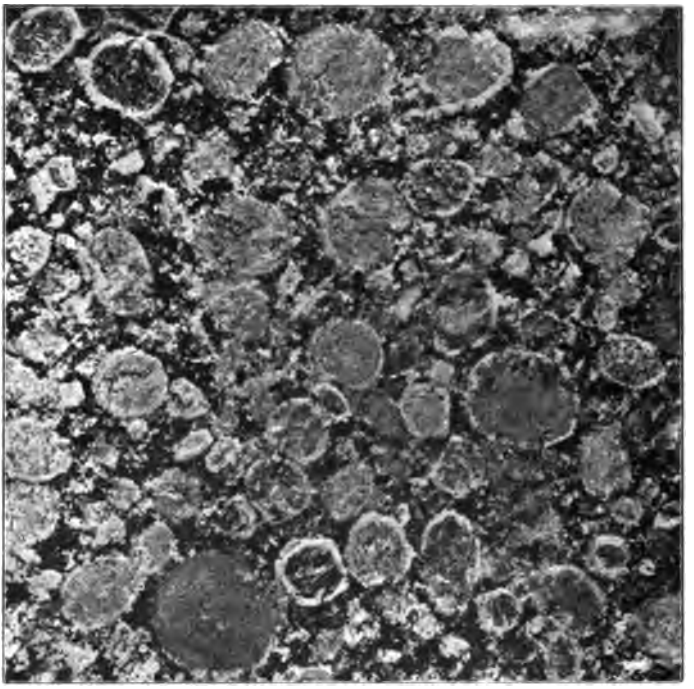

Fig. 3. Rapakivi from Luumäki, W. from Wiborg. $^1/_2$ nat. size.

distant from the boundary of the rapakivi-massive. Still nearer is the Cambro-Silurian of Esthonia to the rapakivi-quartz-porphyry of Hogland, and these sediments show no signs of metamorphism or of disturbances. Finally, J. G. Andersson has found a boulder of a conglomerate with *Torellella lævigata,* which contains pebbles showing the characteristical micro-pegmatitic texture of the rapakivi-rocks. This fact proves that there already existed such rocks in Fenno-Scandia in pre-Olenellus time.

Dala-Quartz-porphyries and Dala-Granites. In Dalarne in Sweden there are extensive sheets of quartz-porphyritic rocks gradating into granites which possess some likeness to the rapakivi-rocks, but are distinguished from these by several characteristics, in part primary, in part secondary. They show signs of having undergone a slight metamorphism. On the map they have been simply designated as Dala-quartz-porphyries and Dala-granites. They are, however, geologically more closely related to the Jotnian rocks than to the rocks forming their basement.

Fig. 4. Pebble with adjoining matrix from a conglomerate of probably post-Jatulian age. Jokijyrkkä, Pudasjärvi in northern Finland. $^3/_7$ nat. size.

While the absence of more conspicuous „dynamo-metamorphic" phenomena among the Jotnian rocks is very remarkable, and while they stretch in an almost continuous belt over central Fenno-Scandia, crossing the predominant strikes of the older rocks of that region, all pre-Jotnian rocks have been more or less strongly metamorphosed before the time of the deposition of the Jotnian sediments.

The „Almesåkra-formation" of southern Sweden (S.E. from Lake Wettern) consists of sandstones aud conglomerates which show only slight signs of dynamo-metamorphism, and are covered by diabases which are also very little altered. They have been indicated on the map in the same colour as the more highly metamorphic Jatulian rocks, but are probably somewhat younger than these, possibly nearer related to the Jotnian.

N. of Lake Uleå in Finland (E. of Uleåborg on the Gulf of Bothnia) there is an isolated patch of conglomerate (not shown on the map) which is also possibly of post-Jatulian age, but in which the pebbles show the most conspicuous marks of having undergone a strong pressure. (Fig. 4).

Jatulian Quartzites and Schists. This division is best developed in Carelia in the eastern part of Fenno-Scandia. Its main constituents are white quartzitic sandstones in a more or less strongly

metamorphic condition, often, however, showing an evidently clastic texture, ripple-marks (Fig. 5), and thin intercalations of mudstones

Fig. 5. Jatulian quartzite showing ripple-marks from Kuusamo in northern Finland. C. $^1/_5$ nat. size.

Fig. 6. Jatulian conglomerate. Raatevaara, Kiihtelysvaara in eastern Finland.

with suncracks. Conglomerates with pebbles of granite or glassy quartzites are common, especially at the base (Fig. 6). Overlying

these quartzites there occur dolomitic limestones, which are often cavernous and remind one of coral-rocks, and argillitic slates, with an intercalation af anthracite (in Suojärvi in Finland and by Schunga in Olonetz, where this bed measures about 2 m or 7 feet in thickness); further metamorphosed basic rocks („metabasites"), augite-porphyries and their tufs, &c.

The last mentioned rocks, together with some dolomites, slates, sandstones, and the anthracitic beds have been referred by Wilhelm Ramsay to a separate „Onegian" division. But they are now included also by him in the Jatulian, forming its upper subdivision, because there is no marked unconformity between the two formations. However, the Upper Jatulian rocks are less metamorphic than the Lower Jatulian. These are everywhere folded, the dips being generally from 30° to 60°. The strikes in S. E. Fenno-Scandia

Fig. 7. Section from Suunnujoki to Hirveskoski in Olonetz showing Jatulian quartzites and metabasites (black), unconformably overlying the upturned Kalevian quartzites with their conglomeratic intercalations. The parts where the rocks are entirely covered with drift are left white. Scale 1 : 80.000. Drawn by Professor Wilhelm Ramsay.

are predominantly N.N.W. or N.E. (cf. the map) but turn in northern Finland to a more W.—E.-ly direction. The thickness of the whole division is about 2000 m.

The „Dalformation" of the western shore of Lake Wenern in Sweden shows great resemblance to the Jatulian rocks of eastern Fenno-Scandia. Its total thickness is nearly 2,000 m. or 7,000 feet, and it consists of basal conglomerates, quartzitic sandstones, slates with intercalations of limestone and metamorphosed greenstones. Most Swedish geologists seem to agree that it was folded in pre-Cambrian times, but while some of them think that it may be contemporaneous with the unfolded sandstone-formation of Dalarne, referred by the author to the Jotnian division, others think that there may be an unconformity between them. This is also the opinion of the author of the map. After personal study of the localities, he has found no corroboration of the alleged correlation with the „Dala-sandstone". [1]

[1] The reader must not confound the word Dal (=Dalsland) with Dalarne (=Dalekarlia), in composite words abbreviated Dala-.

If the Jatulian is made to include all such folded pre-Cambrian that are younger than the Archæan granites of central and eastern Fenno-Scandia, the Dalformation would be included in this division.

The rocks of the „Telemarkenformation" of southern Norway have here been indicated by three different colours, following the example of a Swedish map of Scandinavia. But it was only in want of special colours and more detailed knowledge about these interesting formations, that the same colours were used which indicate other formations in the eastern parts of Fenno-Scandia. Considering the greatness of the intervening distance, every correlation between formations in the most distant parts of that region must be a mere guess. The Norwegian geologists seem to regard the different parts of the Telemarkenformation, at least provisorily, as equivalent or nearly related to each other.

The rocks of Lapland and Kuusamo (W. from the White Sea) referred to the Jatulian division are closely analogous to those of eastern Fenno-Scandia both petrologically and in their relations to other rocks. In the region N. from the innermost part of the Gulf of Bothnia it is more difficult to distinguish the Jatulian rocks from the next older.

Among Russian geologists the idea has been prevalent from older times that the rocks of Olonetz referred here to the Jotnian, Jatulian and also to the next older, Kalevian, divisions, are Carboniferous and Devonian rocks in a metamorphic condition. But none of the alleged discoveries of fossils in these rocks has stood the test of criticism, nor has it been proved that there are any transitional links between these different formations.

A glance at the map is enough to show how impossible is the assumed correlation. It is obvious, that the folded formations in question, with their decidedly N.W. strike, dive in under the horisontally overlapping Devonian and Carboniferous in the region S.E. of Lake Onega. The Fenno-Scandian region must here, as in southern Sweden, be limited by faults.

Post-Kalevian Granite. Kalevian „Metabasites" (Plagiamphibolites), Kalevian Quartzites and Schists, &c. The progress of the detailed investigation of the quartzitic formations of Finnish and Russian Carelia, and the adjacent part of Lapland, has led to a continued subdivision of formations which in the beginning were thought to be contemporaneous. In Finland, the greater part of the pre-Jotnian quartzites were referred till 1902 to a single forma-

tion. But then it was shown, by Frosterus in Finland and Ramsay in Olonetz, at the same time, that there existed at least two formations of folded quartzites. For the older of these the name KALEVIAN was proposed.

The Kalevian quartzites (Fig. 8) have also originally been sandstones, but they are now in a more highly metamorphic condition than the Jatulian rocks. They are often glassy and commonly contain muscovite also in great flakes (not sericitic), and

Fig. 8. Kalevian quartzites dipping at a low angle. Petrovaara, Juuka in eastern Finland.

gradate into muscovite-schists. But some varieties are even macroscopically very much like sandstones and show distinct crossbedding (Fig. 9), but more seldom ripple-marks. They are intercalated with conglomerates (Fig. 10 und 11), phyllites, „metabasites", chloritic and talc-schists, dolomites &c. The thickness is difficult to determine because of the great amount of metamorphism and dislocation and the frequent patchy character of the remaining parts of these sediments which must have formerly had a very great extension over the whole of Fenno-Scandia. Probably they have been originally several thousand meters thick. In Lapland this formation can be subdivided into two parts, separated by an unconformity that is

marked by basal conglomerates with pebbles of the underlying rocks.

In the same region, and still more conspicuously in Olonetz, the unconformity between the Kalevian and the Jatulian rocks, resting on their upturned edges, and containing, in their basal conglomerates, pebbles of the Kalevian rocks, is often very well developed (cf. fig. 7).

The separation of the Kalevian from the underlying rocks is often, especially in eastern Finland, more difficult, because formations of different age have here been repeatedly folded together at different

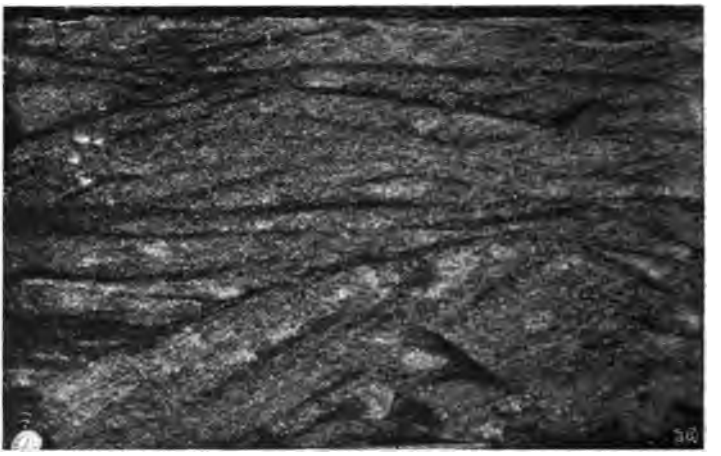

Fig. 9. Upper Kalevian quartzitic sandstone. Sodankylä, Finnish Lapland.

times. Some geologists have therefore included in that division rocks which are here referred to an older division. Possibly there are also quartzites whose age is intermediate between this division and the Kalevian, and which can in the future be separated from both of them.

In south-eastern Fenno-Scandia there seem to be no other granites younger than the Kalevian rocks except the rapakivi. But in Lapland there are granites of very wide extension which penetrate the Kalevian rocks, even the youngest, sandstone-like quartzites, and form with them veined („migmatitic") gneisses.

The extension of the post-Kalevian, but pre-Jatulian granites and of the Kalevian schists in northern Sweden is difficult to determine, there having been no attempt made to correlate the rocks

on either side of the frontier by tracing them in the field from point to point. It is possible therefore, that a large proportion of the

Fig. 10. Kalevian conglomerate from Heinävaara in Kontiolaks, eastern Finland. $^1/_7$ nat. size.

granitès of northern Sweden here mapped as post-Kalevian, and perhaps also of the schists of the same region which have the

same N.—S.-ly strike as the Kalevian, and have been mapped as belonging to this division, may be still older. If this were so, the extension of the post-Kalevian granites and Kalevian schists would be restricted mainly to the Finnish side, and the map would in this part be erroneous.

In Finland a narrow strip of the last mentioned granite reaches as far southward as to the neighbourhood of Kajana, S. of Lake

Fig. 11. Kalevian conglomerate whose pebbles are loosened by weathering. Lake Kuivajärvi in Kuolajärvi, N. E. Finland.

Uleå, and it is possible that some also of the granites in the region between Kajana and Lake Ladoga may belong to the same group. In any case, the formation of the N.W. strikes of the Kalevian schists and the protrusion of the post-Kalevian granite must have occurred simultaneously. The N.W. strikes predominate in eastern Fenno-Scandia, and the extension of the granitic area follows the western limit of the most continuous belt of Kalevian schists, and its longer axis is parallel with their strike.

A similar N.—S. strike is found in the area of gneissose granites of south-western Sweden. Where there are sediments of pre-

Cambrian age near to that area of gneisses, they have also the same N.—S. strike. But in the central region of Fenno-Scandia, on both sides of the northern Baltic and the Gulf of Bothnia, which displays greater complexity in its geological structure than the districts to the east and southwest, the strikes show also a greater variety. E.—W.-ly strikes are here prevalent, especially in southern Finland and middle Sweden, where also the longer axes of the granitic areas predominantly are parallel with that direction. But on the S.W. margin of this region there is again, in Småland in Sweden, a large area of granites, which show great resemblance to the post-Kalevian granites of northern Finland. The longer axis of this granitic area follows the N.—S. direction of the boundary between the gneissose area and central Fenno-Scandia, and intersects the E.—W. strikes which are apparently of older date. The granites of Småland are referred by Törnebohm to a younger group than the main part of the granites of middle Sweden. On the margins of the granitic area of Småland occur quartzitic schists (at Vestanå in Scania and at Westervik) which have a certain resemblance to the Kalevian schists of eastern Fenno-Scandia. They are the only schists of southern Sweden which may possibly represent this series, which is so well developed in eastern Fenno-Scandia.

The author has therefore suggested as a working hypothesis, that the great movements which have separated central Fenno-Scandia from the gneissose regions bordering it in N.E. and S.W., may possibly have been contemporaneous on either sides of that central region, and that thus the granites of southern Sweden may be post-Kalevian, the quartzites bordering it of Kalevian age.

Granulite (Leptynite). Garnetiferous Amphipolitic Gneiss. The granulites of Lapland are rocks whose origin is still in many respects an unsolved problem. The most typical of them are fine-grained garnetiferous schists of granitic composition, similar to the lighter varieties of the Saxonian granulites (Fig. 12), while others are more coarse-grained and can be designated as garnetiferous gneisses. They often show conspicuous marks of having undergone strong mechanical pressure; but the formation of the feldspathic veins common in these rocks seems also to have been connected with processes of resolution or refusion („anatexis") of the pre-existing material which was in the main granitic. This metamorphosis was anterior to the intrusion of the youngest of the post- Kalevian granites, but it cannot yet be ascertained, whether it happened after the

deposition of the Kalevian sediments or in pre-Kalevian time, possibly in connection with the eruption of the next older (post-Bottnian) granites. The highly garnetiferous amphibolitic gneisses (or schists) of the same region probably also received their present character at the same time as the granulites.

Post-Bottnian Granite; Massive Granites in general of undetermined age. Quartz-porphyries and Hälleflintas among the Older Rocks. Bottnian Schists. The Kalevian formations take an intermediate position between the pre-Cambrian of „Algonkian" (or Archæozoic)

Fig. 12. Specimen of granulite (leptynite) from Kultala, Enare in Lapland.

type, the sediments of which are separated by evident unconformities from their underlying basal complex, and the oldest Archæan complex, whose different parts are so closely interwoven by granites, that the existing unconformities can only be detected locally. The sedimentary rocks of this complex have been subject to very great disturbances, so that the dips are generally almost vertical, and they are often in a highly metamorphic condition.

However, they occasionally show primary characters astonishingly well preserved. This is especially the case with the Bottnian schists of S.W. Finland. These are best developed near to the town of Tammerfors, on both sides of Lake Näsijärvi. Their lower division consists of phyllites (3,000 m), showing under the micro-

scope very distinct clastic textures and, even to the naked eye, an alternation of thin layers originally sandy, often distinctly crossbedded, and others which are almost aphanitic and may have been, in their primary condition, clays (Fig. 13). The alternation is exceedingly regular, the sandy layers lying always to the south, i. e. on the side of the former basement, while the originally clayeous layers form the northern (upper) part of each composite stratum. There is always a sharp dividing plane between the finest part of each stratum and the coarsest part of the next in succession. The phenomenon is strikingly similar to the bedding of the Quarternary glacial clays of the same region. Their bedding has certainly been caused by the alternation of the seasons, each summer bringing, at the melting of the ices, abundance of water and therein suspended sediments, while in the winter only the finest mud, that can long remain in suspension, was deposited. Since the author can think of no other recurrence of conditions influencing sedimentation, of the same regularity, as that of seasons (either wet summers and cold winters or periods of dryness and rain) he is inclined to explain the phenomenon observed in the Archæan sediment in a decidedly uniformitarian way, as indicating the existence of seasons already at that early date. He is now endeavouring to get an exact measurement of the total number of composite layers in the whole formation; a preliminary rating gave an average thickness of 10—15 cm, which would make the time for the deposition of the maximum thickness less than 50,000 years. But it must be remembered that the maximum thickness of one part of a sedimentary formation does not contain all the individual layers forming it; for these are frequently deposited one over the other like scales or roof-tiles. The number contained in the maximum thickness gives only a minimum of the amount of time required for the deposition of the whole formation.

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[1] There seems to be a general tendency in America to regard the rocks of LOWER HURONIAN age as belonging to the oldest sediments that ever have been deposited. It must therefore be emphasized that the sedimentary rocks of Fenno-Scandia which resemble them most petrologically, and which have a similar stratigraphical position, i. e. the Kalevian rocks, are separated from the oldest basement of granitic gneisses not by one, but by several great sequences of sedimentary rocks, whose conditions are more or less metamorphic, in the same degree as they are mixed with granitic rocks. There seems to be every reason to assume that these older Pre-Cambrian sediments, which should thus be analogous with the pre-Huronian (Kewatin) rocks of North America, comprise the major, not the minor part of the bulk of the pre-Cambrian sediments.

The author makes this digression from the regular course of his description of the map, which must of course be a summary one, in order to show in what degree [illegible] ideas must suggest

Fig. 13. Bothnian phyllite, showing regular alternation, of layers originally sandy and clayeous.

themselves to the mind of the investigator of these very old rocks. There is abundance of other evidence in the same direction. The conglomerates which occur in these formations (Fig. 14) and sometimes possess a thickness of several hundred meters, show very clearly

their original constitution in spite of their present crystalline character. They contain pebbles of a great many different rocks, among them even granitic. Together with the conglomerates, and forming with them the upper part of the Bottnian at Tammerfors, are other bedded schistose rocks which are metamorphosed tufs and sometimes intercalated with volcanic sheets (metamorphosed andesites and uralite-porphyries).

Fig. 14. Bottnian conglomerate with schistose matrix from Veittijärvi in Ylöjärvi, near to Tammerfors in Finland. $^1/_7$ nat. size.

S. of Tammerfors there is another belt of similarly metamorphosed Archæan volcanic rocks, mainly uralite-porphyries with their tufs, often in a highly metamorphic condition. The same rocks occur also in islands on the northern coast of the Gulf of Finland.

In Ostro-Bothnia, S.E. of the interior of the Gulf of Bothnia, there are similar schists, containing conglomerates, uralite-porphyries, phyllites, etc., and in Skellefteå on the Swedish side there occur schists which show, according to the description of Högbom, the

most striking resemblance to the Bottnian rocks of Tammerfors. Especially is this true of the schistose conglomerates.

In middle Sweden also, N.E. of Lake Wenern, there occur schists (at Grythyttan, Los, etc.), among them conglomerates, „metabasites" and more acid eruptives, which have very much the same character as the Bottnian rocks, and may provisionally be correlated with them.

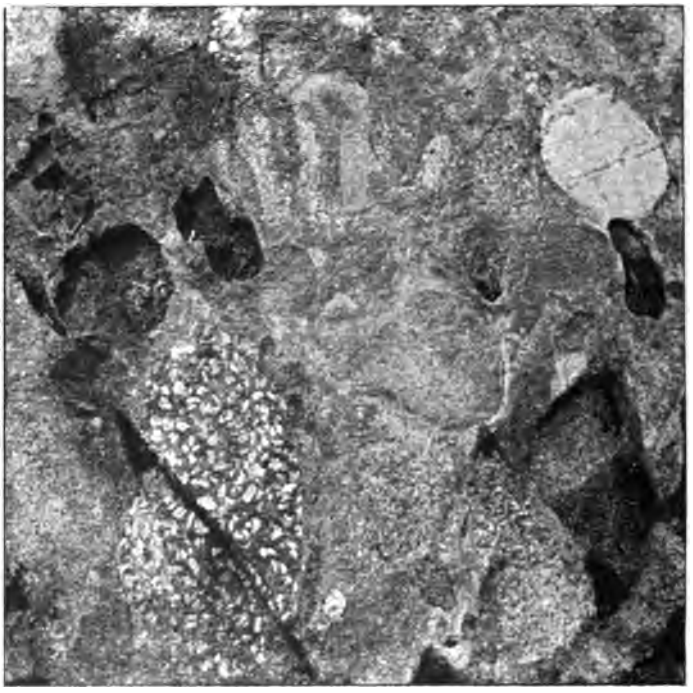

Fig. 15. Bottnian conglomerate with gneissose matrix from Harju in Suodeniemi, N.W. from Tammerfors in Finland. $^1/_5$ nat. size.

The metamorphosed volcanic rocks occurring in the typical Bottnian formations of Finland are mostly basic, quartziferous rocks being infrequent among them. But in the Archæan of Sweden it is very common to find rocks which were originally quartz-porphyries or rhyolites, or tufs connected with them, but are now metamorphosed in lesser or higher degree. The greater part of the rocks known in Sweden under the name of hälleflintas seem to be of such origin. Also in southern Finland there are similar quartz-porphyritic rocks.

There is in Sweden a general tendency to regard all quartz-porphyritic rocks as belonging to one and the same geological formation. But there can be little doubt that there are quartz-porphyries of very different ages in the pre-Cambrian complex of Fenno-Scandia, some being, as stated above, connected with the rapakivi, others with the Dala-granites, some nearly related to the post-Kalevian

Fig. 16. Porphyritic post-Bottnian granite from Lavia in Finland. $^1/_5$ nat. size.

granites, while the greater part seems to be as old as, or even older than the Bottnian schists.

All the last-mentioned schistose rocks are penetrated by granites, similar to the younger Archæan granites occurring in the basement of the Kalevian. These post-Bottnian granites (Fig. 16), which are widely extended over central Fenno-Scandia, are petrologically very varying but geologically closely connected, often forming great continuous areas. Of those the most important are the central granitic area of Finland and the granitic area of Norrland in Sweden. The granites of these areas show many similarities.

A coarsely porphyritic texture is very common, and both areas are bordered with belts of Bottnian schists.

The area of post-Bottnian granites extending from S.W. Finland to middle Sweden (or „the Sveco-Fennic zone") is of a different constitution. Only a few of these granites are similar to those occurring in the central areas and are quite massive, while others are gneissose, interwoven with or containing patches of more or less completely assimilated older rocks, forming with them com-

Fig. 17. Migmatitic gneiss, formed by the injection of post-Bottnian granite into a metabasite. Tvärminne, W. from Hangö in Finland.

posite gneisses („migmatites", Fig. 17). They are also very often garnetiferous. The massive and gneissose varieties gradate into each other, and although some of them occur in areas which are more independent, they have not been separated from the remainder on the map.

Where there are no schists of characteristic appearance near to the granites, or where the contact-relations of these rocks have not been studied in sufficient detail over wide areas, it is of course often very difficult to determine the age of each granitic mass. As the post-Bottnian or younger Archæan granites seem to possess

the widest extension of all massive pre-Cambrian granites, the granites of unknown age have been designated with the same colour as these. As already remarked, the age of the granites of northern Sweden is uncertain and they might perhaps have been more correctly mapped as post-Bottnian, not as post-Kalevian, as has been done on the map. The same is true of the granite of Bohuslän in Sweden, S.E. of Christiania. It is very similar to the Stockholm-granite and other granites occurring in the Sveco-Fennic zone, and may possibly also be of post-Bottnian, not post-Kalevian, age. As to the granites of southern Norway mapped as post-Bottnian, it has already been remarked that some of them penetrate the quartzites of Telemarken. If these, or some of them, could be regarded as equivalents of the Kalevian, or Jatulian, the granites would, in consequence, be post-Kalevian or post-Jatulian. It is only where the granites show a very characteristic and, broadly considered, uniform petrological character and are in contact with continuous zones of sedimentary rocks of well known age, that their own age can be determined with full certainty. In other cases, they must provisionally be grouped together with such granites of the adjacent regions as they most resemble.

According to the system which has been employed in mapping the pre-Cambrian rocks of Finland, every granite which has apparently been in a fluid condition after the deposition of any given sedimentary formation, is regarded as younger, irrespective of the question whether its magma is of „juvenile" origin, or has been formed by the melting of a former basement. It is, the author thinks, not compatible with the principles of sound geological classification to give, as has been done with the s. c. „Laurentian" of Canada, a different name to a supposed basement which is proved to have intruded into the sediments which possibly once rested upon it, or to place it below these sediments in the geological succession.

The granitisation which has befallen all rocks of central Fenno-Scandia older than the Kalevian has probably been the chief cause of the intense metamorphism which they have suffered, and has also done much to obliterate their original stratigraphy. The disturbances have been exceedingly great, so that almost all strata originally horizontal are now vertical. Thrusts have often separated the sediments from their former basement, and granite has been injected along the contact-planes. The unconformities which have once

existed here can therefore only be recognised in those localities, where the primary features are better preserved than is usually the case.

Older Archæan Schists (of Ladogian or undetermined age). Micaceous Gneisses. Gneissose Granites and Granitic Gneisses; Archæan in general, uninvestigated in detail. Many of these Archæan schists of central Fenno-Scandia which are presumably of sedimentary origin seem to be even older than the Bottnian schists and the granites and gneisses formed subsequently to their deposition.

Fig. 18. Strongly folded Ladogian mica-schist from the island Karponsaari in Lake Ladoga.

Among the rocks of S.W. Finland which must be reckoned as belonging to the pre-Bottnian basement are mica-schists, glassy quartzites, limestones, &c., which possess the constitution of metamorphosed sediments, together with „metabasites" and other intercalated eruptive rocks. They are, in general, still more metamorphic and have been in still larger measure invaded by granites than the Bottnian schists. Their primary textures are therefore only very occasionally preserved, conglomeratic schists with well recognisable pebbles being seldom found. The stratigraphy also shows, in gen-

eral, very few of its original features, the rocks having been disturbed, folded and crumpled, often to the utmost degree (Fig. 18). In the region N.W. of Lake Ladoga, however, rocks which resemble some of the older schists of S.W. Finland show clearer relations to each other and to their basement of granitic gneisses. These form oval areas, surrounded by the schistose formations which show a succession of strata of different constitution, following each other in regular order. The total thickness of these schists, which have

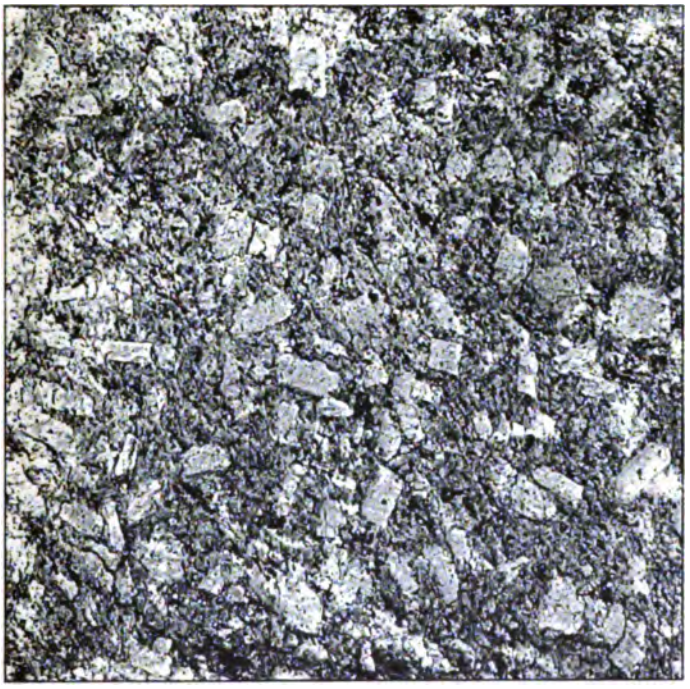

Fig. 19. Porphyritic pre-Bottnian granite from Orivesi in southern Finland.

been called Ladogian, is at least several thousand meters. Where the schists are not transformed to gneissose rocks by granitisation, they contain often in abundance andalusite, staurolite, garnet and other contact-minerals. In some of these schists have been found conglomeratic structures, but it is not yet decided for certain whether these rocks belong to the Ladogian, or form a highly metamorphic part of the adjacent Kalevian.

The granites which penetrate these schists of western Finland that are similar to the Ladogian, but in every case pre-Bottnian,

are strongly dynamo-metamorphic (Fig. 19), gneissose in character, and would be called gneisses by many geologists. The greater part of the rocks designated on the map as micaceous gneisses are, however, rocks of another description. They are heterogeneous rocks, composed of a mixture of darker, schistose parts and lighter granitic veins, which have either been injected from below or created by the refusion („anatexis") of the rockmasses which they now interweave (Fig. 16).

According to this view there have been formed veined or „migmatitic" („mictositic") gneisses every time that great disturbances have brought sedimentary schists or granites with schistose texture into close proximity with the great abysses of molten magma underlying the earth's solid crust. Thus, there exists no „gneissformation" occupying any definite position in the geological succession. As stated above, veined gneisses have been formed at different epochs since the post-Ladogian age, but the post-Bothnian granites seem, when penetrating from below, to have especially tended to form large quantities of gneisses. Or, in other words, denudation in central Fenno-Scandia has proceeded far enough to expose over great areas, just those depths which were, in the age succeeding the deposition of the Bottnian sediments, on the border between the solid crust and the underlying masses of latently fluid magma, or were penetrated by great apophyses from them.

The oldest granitic gneisses, which form the greatest areas of such rocks in Fenno-Scandia, alone seem to possess another possible origin. Those on the shore of Lake Ladoga seem to be anterior even to the oldest sedimentary Archæan schists of this region, and there are also other regions, in which there have not yet been found any presumably sedimentary schists penetrated by these granitic rocks. Thus they must be either parts of the crust solidified before the deposition of sediments began in the district, or very old batholites which have been deeply eroded in pre-Ladogian time. The fact that they show, both in Sweden and Finland, features which are not found in later granites seems to lean rather towards the first mentioned hypothesis.

It is impossible now to determine their distribution with certainty, because these great areas of granitic gneisses also contain many gneissic and granitic rocks af later date which cannot, at the present stage of our knowledge, be separated from them.

The explanation of the difference in structure between central

Fenno-Scandia and these great border-areas of granitic gneisses, and the problem of their relations to each other belong to the most important questions of Fenno-Scandian geology, and are by no means yet definitely settled.

In general, most of the difficult questions of the pre-Cambrian geology of Fenno-Scandia which have been here only touched upon are still open to further controversy. It is, however, proved with certainty that there exist in this region, probably in richer development than in any other area which has been investigated in similar detail, great sequences of pre-Cambrian sedimentary formations, separated by many gaps from each other, which give one a picture, growing less distinct in outline the further back one goes, of the remotest periods of geological history, or, in other words, of periods of the earth's pre-historic age, which is, according to the author's opinion, probably of greater length than all the subsequent geological time. But the true sequence of the manifold sedimentary and eruptive rocks has only been worked out in sufficient detail on limited areas. It remains to try the same methods on the material still left uninvestigated, or such as has been mapped according to antiquated methods. Continued researches will, no doubt, change very many of now prevailing opinions and will certainly also add still further links to the already discovered remnants of the ancient formations here preserved. But it may not be extravagant to hope that they will not entirely change the features of the geological structure of Fenno-Scandia, which this summary sketch-map of the region, the first which shows also its manifold pre-Cambrian formations, endeavours to represent in their main outlines.